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SEED FLAX STRAW--

Potential for Extending its Utilization

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SEED FLAX STRAW--
Potential For Extending Its Utilization[1]

By George H. Goldsborough[2]

INTRODUCTION

The industrial utilization of seed flax straw, including the whole straw and the bast fiber and shive fractions, has been extensively researched in the United States and Canada by public agencies, both Federal and State, and by private industry. Literature on the subject dates back to 1902. At the present time (1962), about 30 percent of the economically available straw, or 200,000 tons, is decorticated for use in cigarette paper manufacture. This provides most of the fibrous raw material for domestic and export requirements of such paper.

The appraisal described in this report was conducted to reexamine the feasibility of using additional quantities of seed flax bast fiber in various end uses: textiles; twine and cordage; cellulose-sponge reinforcement; bond, currency, and other specialty papers; coarse paper and insulation board; nonwoven goods; and absorbent pads. These markets are presently served by line (fiber-type) flax, cotton, jute, wood, and other natural fibers and by synthetic fibers. In the past year (1961) there has been renewed interest in extending the use of seed flax straw because of efforts to commercialize a number of new processes.

The information appraised in this report comprises primarily data on the various laboratory, pilot-plant, and commercial efforts to utilize seed flax straw by public and private organizations in the United States and Canada from 1902 to 1960. The three techniques used in assembling the data included (1) a literature search; (2) a review of files covering previous public and private research and pilot-plant efforts; and (3) discussions with qualified individuals aware of the availability and utilization of seed flax straw and line (fiber-type) flax.

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BACKGROUND

Cultivated flax probably originated in the Mediterranean region from the wild flax. It reached the United States during the colonial period, where it was widely grown for fiber before the invention of the cotton gin in 1792 made cotton a cheaper fabric. The manufacture of linseed oil in the United States began in 1805.

There are two major types of flax--varieties produced principally for fiber and varieties produced principally for seed. Fiber-type varieties are closely planted; they have long stems with few branches and seeds. The long fine linen, or bast fibers, occur in the bark of the stem and comprise about 15 percent of the straw by weight. Seed flaxes are planted sparsely; they have short, much branched stems and many seeds. The bast fibers also occur in the bark, but they are considerably shorter and somewhat coarser than those produced from fiber-type flax.

Fiber Flax

The world produces about 700,000 to 1,000,000 tons of flax fiber on from 2,000,000 to 3,000,000 acres annually. Fully three-quarters of this is produced in the U.S.S.R. Other leading countries include Poland, Germany, France, Northern Ireland, Ireland, Rumania, Belgium, and Holland; some is also produced in New Zealand, Australia, Japan, Argentina, and Egypt. In the United States fiber flax was produced in limited quantities in the years immediately prior to World War II. During the war, production was expanded somewhat to fill emergency needs, but the industry steadily declined thereafter with no commercial production since 1953.

Flax is harvested for fiber when about one-half of the seeds are ripe and the leaves have fallen from the lower two-thirds of the stem. This stage usually is reached about 80 to 100 days after sowing.

The seed is saved for sowing purposes, oil extraction, or feed.

The fiber is separated from the woody core by breaking, or scutching, hackling, and combing. Breaking is accomplished by passing the straw between fluted rolls or by crushing it between slatted hand-breaking frames. This breaks the brittle woody parts of the stem into short pieces called shives, but leaves the flexible fibers largely intact. Scutching is accomplished by passing the broken straw through revolving beaters, or turbines, that free the fibers from the shives. Some machines do both breaking and scutching. The scutched fiber is baled and shipped to spinning mills. At the spinning mill the fiber is hackled by machines that comb out the short, tangled fibers and remaining shives. The resultant long straight fiber, called line fiber, is further combed and then twisted into yarn on a spinning machine. Coarse yarns may be 2,400 yards per pound, while the finest yarns are 36,000 yards per pound. The short or tangled fibers, called tow, may be carded to produce strands of parallel fibers that are then spun into coarse yarns, or the tow may be used for upholstering, padding, and papermaking. Fine yarns are used in weaving high-quality linen fabrics, such as laces, household linens, and dress goods. Coarse yarns are used for kitchen toweling or other coarse fabrics or for making twine, cord, or rope.

Seed Flax

The world production of flaxseed (linseed) is about 130,000,000 bushels from more than 19,000,000 acres. About an eighth of this is obtained as a byproduct from fiber flax and the rest is produced by seed-flax varieties. Seed-flax yields are about twice those of seed from fiber flax under similar conditions. The United States, Argentina, the U.S.S.R., India, Canada, and Uruguay are the leading countries in linseed production, but appreciable quantities are produced in 25 other countries on all continents. Production in the United States ordinarily averages about 32,000,000 bushels; about 90 percent is produced in North Dakota, Minnesota, and South Dakota.

In the United States seed flax is combined from the windrow, and the straw residue left in

the fields constitutes a disposal problem to producers. Apparently, growers prefer not to plow the straw under, because its slow rate of decomposition adversely affects the yield of succeeding crops in the rotation. Therefore, much of the straw finding no commercial use is burned in the fields. Because of this fact, plus the availability of bast fibers in the straw, the commercial utilization of the residue in textile, paper, and other products has been the subject of extensive research and development by public and private agencies since about 1902.

AVAILABILITY OF SEED FLAX STRAW

Since World War II, the harvested acreage of seed flax reached its highest levels, 4,500,000 to 5,600,000 acres (19),[3] in the years 1948-49 and 1953-57 (table 1). The volume of residual straw available from this acreage (the seed being the primary product) ranged from about 1,500,000 to 1,900,000 tons (estimated yield one-third ton recoverable straw per harvested acre). Since 1957, however, the harvested acreage and, accordingly, the available straw, have declined sharply to immediate post-war year levels--about 3,000,000 acres and 1,000,000 tons, respectively. This decline is reportedly caused by the reduced demand for linseed oil--the principal product made from flaxseed in surface coatings.

Contacts made with representatives of the surface-coating industry indicate that this market--the major outlet for linseed oil--will likely continue for many years to take about the same volume. Water-dispersible linseed oil paints, a recent development, are apparently being well received by consumers. Although with this type of paint the proportion of linseed oil to finished surface coating is less, the total market for surface coatings is increasing sufficiently to keep the requirements for linseed oil at about the present level.

At the present time (1962), about 200,000 tons of straw are decorticated for use in the manufacture of cigarette paper. This provides most of the fibrous raw material for domestic and export requirements for such paper. Of the remaining 800,000 tons, about 60 percent, or 480,000 tons, is produced in areas where flax acreage is rather heavily concentrated and is relatively free of weeds. In these areas it is estimated that straw procurement, assembly, and storage costs would be in line with the costs of the straw presently being used for cigarette-paper manufacture. The balance of the available straw is produced in comparatively scattered areas, and procurement and assembly costs would likely be too high for commercial utilization.

TABLE 1.--Availability of seed flax straw, 1944-61

Year	Acres harvested for seed[1]	Straw available (estimated yield 1/3 ton recoverable per harvested acre)[2]
	1,000 acre	1,000 tons
1944..	2,610	870
1945..	3,785	1,292
1946..	2,432	811
1947..	4,129	1,376
1948..	4,973	1,658
1949..	5,048	1,683
1950..	4,090	1,363
1951..	3,904	1,301
1952..	3,304	1,101
1953..	4,570	1,523
1954..	5,663	1,888
1955..	4,981	1,660
1956..	5,548	1,849
1957..	4,899	1,633
1958..	3,853	1,288
1959..	3,015	1,005
1960..	[3] 3,342	1,114
1961..	[4] 2,514	838

[1] From (19, 20). [2] From (8, 14).
[3] Revised. [4] Preliminary.

This estimate of the economically available straw represents an average year. The degree of constancy of this availability from year to year was somewhat controversial among the persons interviewed. The availability of straw should, therefore, be the subject of an "on the spot" special survey before any new enterprise using seed flax straw is undertaken.

[3] Underscored numbers in parentheses refer to Literature Cited, p. 19.

Domestic Seed Flax Fiber

Cigarette paper and other special papers.--Prior to the 1930's most of the cigarette paper used in this country was imported. In 1938-39, after substantial research and development effort, three paper companies (3, 13) began the manufacture of cigarette paper from decorticated domestic seed flax bast fiber. Each company contributed to the work culminating in this new use for seed flax straw.

Two United States companies supply practically all the domestic requirements for cigarette paper (small quantities are imported) and, as indicated earlier, use about 200,000 tons of straw annually. A company at Beauharnois, Canada, is also producing cigarette paper from Canadian-grown seed flax. The market for cigarette paper is growing at a rate of 4½ percent per year. Small quantities of the decorticated fiber are also used in making Bible paper, airmail stationery, carbonizing paper, and currency paper.

The straw is procured shortly after combining, in some instances with little or no retting, decorticated in the flax-production area, and the bast fiber, with almost an equivalent weight of gums and adhering shive particles (somewhat better than 33 percent fiber to original straw), shipped to the papermills in the East. The fiber used by one company is decorticated at a central plant in the major flax producing area and the other company operates several smaller decorticators at locations where production is most concentrated.

The straw is procured in baled form from custom balers or from farmers and, in many instances, is transported to the decortication plants for storage. Farmers sometimes contract to store the straw on their own property until it is required for processing. Farmers reportedly receive about $2 per ton from custom balers for their straw (4). Farmers who bale their straw receive the margin normally going to custom balers. The operators of the decortication plants report that costs involved in procuring, baling, storing, and transportation to the decortication plant (including $2 to producers) total $22 per ton. Total cost of the decorticated fiber delivered to the papermills in the East is about $0.055 per pound (including $0.01 per pound for transportation).

About 5 percent of the flax fiber required is obtained from overseas sources and from domestic linen-thread and towel makers in the form of line flax (fiber-type) waste at $0.04 to $0.07 per pound. Line flax waste imported for papermaking carries no duty.

Cattle feed, poultry and animal litter, foundry conditioner, fuel.--At the present time (1962), most of the shive, the residual material from the cigarette-paper fiber decorticating process, is dumped and burned. However, limited quantities are being sold for poultry and animal litter, as a low-grade ingredient in cattle feed, and as a foundry conditioner for core oils. Small amounts are also used as fuel for the central decorticating plant. As a fuel, shive has a value equal to 5,500 B.t.u. per ton--almost one-half that of coal.

The firms concerned with flax straw decortication are continuing to seek ways of utilizing the residual shive. Some report the prospects are encouraging for expanding the market for litter.

Line (Fiber-Type) Flax Fiber

Many of the uses for which seed flax bast fiber and shive are proposed are presently being served by imported line (fiber-type) flax fiber. This section presents the size of the market for line flax, trends in the market, and the competition it will present in terms of properties, availability, and cost for the various end uses envisioned for seed flax fiber.

Textiles.--The market for line (fiber-type) flax for textile purposes has declined materially since the 1920's and 1930's (table 2) and has leveled off (1959-60) at a total of about 3

TABLE 2.--Mill Consumption of Various Fibers, United States, Specified Years

Fiber	Volume Consumed in--						
	1913[1]	1919[1]	1929[2]	1939[2]	1949[2]	1959[2]	1960[2]
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds
Cotton	2,709.3	2,859.7	3,425.3	3,628.6	3,839.1	4,335.2	4,216.6
Rayon and acetate	4.0	9.3	133.4	458.9	993.5	1,252.3	1,055.7
Other synthetics	0	0	0	0	92.8	812.3	821.6
Wool	228.3	329.1	368.1	396.5	500.4	429.2	404.2
Flax	25.9	10.1	14.0	14.4	6.1	[3] 3.0	[3] 3.2
Silk	34.0	55.0	96.8	55.3	4.0	8.0	8.6
Total	3,001.7	3,263.2	4,037.6	4,553.7	5,435.9	6,840.0	6,509.9

Fiber	Percent of total in--						
	1913[1]	1919[1]	1929[2]	1939[2]	1949[2]	1959[2]	1960[2]
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Cotton	90.3	87.6	84.9	79.7	70.6	63.4	64.8
Rayon and acetate	.1	.3	3.3	10.1	18.3	18.3	16.2
Other synthetics	--	--	--	--	1.7	11.9	12.6
Wool	7.6	10.1	9.1	8.7	9.2	6.3	6.2
Flax	.9	.3	.3	.3	.1	([4])	([4])
Silk	1.1	1.7	2.4	1.2	.1	.1	.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] From (6).
[2] From (17).
[3] Estimated. Imported line flax fiber only; no domestic fiber produced for textiles since 1953. Balance of line fiber imports was used in currency-paper manufacture and as a reinforcing agent in cellulose sponges.
[4] Less than 0.05 percent.

million pounds annually--less than one-tenth of 1 percent of the mill consumption of all textile fibers. Since 1953 all the line flax used in this country has come from overseas sources. According to trade estimates, the end-use breakdown of imported line (fiber-type) flax for textiles in 1960 (table 3) is as follows: (a) 350,000 pounds of "noils" ($0.13 per lb.) and 200,000 pounds of cut "tow" ($0.20 per lb.) are blended with cotton (75 percent cotton--25 percent flax) for kitchen toweling; (b) 620,000 pounds of "tow" ($0.20 per lb.), "not hackled" ($0.26 per lb.), and "hackled" ($0.34 per lb.) are used in making linen thread and 100-percent-linen kitchen toweling; (c) 1,700,000 pounds of "tow," "hackled," and "not hackled" fiber are used for blending with rayon for drapery and upholstery covering; and (3) 300,000 pounds of fiber are cut (1 to 3 inches) for blending with dacron, cotton, and rayon for dresses and suits.

Various persons associated with the textile industry in production, sales, and research were asked for their views as to the reasons for the sharp decline in U.S. mill consumption of line flax. The reasons given were that (a) synthetic fibers have made substantial encroachments on the traditional flax- shoe-thread and fishing-line market, and (b) the linen-kitchen-towel market has been hurt by competition from lower cost cotton, cotton-flax, and cotton-flax-rayon blends (both domestic and imported).

TABLE 3.--Quantity and Price of Flax Fiber Imports, United States, Specified Years

Type of fiber	Quantity (million pounds) in--									
	1935	1946	1948	1950	1952	1954	1956	1958	1959	1960
Hackled.....	2.79	1.03	0.11	0.23	0.07	0.02	--	--	0.01	[1] 0.03
Not hackled...	4.75	5.15	3.35	5.12	3.21	3.92	3.58	1.62	.69	[1] 1.27
Tow.....	2.85	12.87	1.53	3.09	2.09	2.36	.35	1.44	2.48	[1] 2.72
Noils.....	.86	.20	--	1.83	.81	.81	.95	.99	.69	[2] .75
Total.....	11.25	19.25	4.99	10.27	6.18	7.11	4.88	4.05	3.87	4.77

Type of fiber	Price (cents per pound)[3], delivered to U. S. port,--									
	1935	1946	1948	1950	1952	1954	1956	1958	1959	1960
Hackled.....	35.2	65.8	72.8	49.0	73.2	36.6	--	--	--	34.0
Not hackled...	23.3	24.7	46.5	33.2	39.2	36.5	27.8	24.0	24.5	26.5
Tow.....	20.5	12.5	14.6	12.9	13.9	13.7	16.6	15.6	16.3	20.0
Noils.....	9.0	17.1	--	10.2	12.5	9.8	12.0	12.2	10.8	13.0

[1] Trade estimates on end use--300,000 pounds of fiber cut and sold for flax-dacron, flax-rayon, and flax-cotton blends for suits and dresses; 200,000 pounds of fiber cut and sold for blending with cotton for kitchen toweling; 1,700,000 pounds of uncut fiber for blending with rayon and other synthetics for drapery and upholstery coverings; 1,200,000 pounds for cellulose-sponge reinforcement; 620,000 pounds of uncut fiber for 100-percent-linen kitchen towels and thread.

[2] Trade estimates on end use--400,000 pounds for currency paper; 350,000 pounds for flax noil-cotton kitchen towels.

[3] Basic price computed from data in (18); duty from Tariff Commission; transportation and other charges estimated. Transportation and other charges $0.0075 per pound; duty 1935, hackled $0.03 per pound, not hackled $0.015 per pound; noils and tow $0.01 per pound; duty 1946 to 1947 hackled $0.015 per pound, not hackled $0.0075 per pound, tow and noils $0.005 per pound; duty 1948 to 1950, hackled $0.015 per pound, not hackled $0.0075 per pound, tow $0.03 per pound, noils $0.0025 per pound; duty 1951 to 1956, no change except reduction to $0.0025 per pound for tow; duty 1956 to 1960, no change except reduction to $0.0125 per pound for hackled.

At the present time (1962), the U.S. production of 100-percent-linen products is restricted primarily to kitchen toweling and thread. In addition, some firehose is made from line flax. The linen towel and thread business is now considered quite marginal and the market declining. Imported line flax firehose is also becoming more competitive (table 4).

The textile mills producing flax noil-cotton and flax noil-cotton-rayon blended kitchen toweling shorten, or "grind," the noils to 1 inch and less in length prior to blending. The starting blend of cotton-flax noil toweling is 60 percent cotton and 40 percent flax. Losses of flax during the spinning operation are such that the finished product is composed of 75 percent cotton and 25 percent flax. Manufacturers making flax-cotton towel blends from cut tow report smaller losses of the flax because the fibers are much more uniform in length.

Flax shortened to 1 inch or less adds nothing to the properties of the toweling, according to the manufacturers, and the blends are produced only to accommodate the small and apparently static market demand for products that may be advertised as having some linen content. The manufacturer's price of such towels is slightly less than that of 100-percent cotton towels.

In contrast to the declining market for line flax in towel and thread manufacture, a small

TABLE 4.--Quantity and Value of Imports of Finished and SemiFinished Flax Textiles, United States, Specified Years[1]

Item	Quantity		
	1935[2]	1946	1950
Flax yarns.....pound..	--	916,039	1,005,819
Flax threads.....do..	--	261,833	310,874
Flax woven fabrics.....do..	11,534,319	258,800	310,044
Flax table damask.....do..	--	636,557	1,650,318
Flax-hemp woven fabrics for padding or interlining.....do..	2,855,710	677,986	553,221
Flax collars and cuffs.....dozen..	14,099	622	1,144
Flax-hemp sheets and pillowcases.....number..	--	100,311	130,499
Flax towels.....do..	--	2,588,908	5,893,966
Flax napkins.....do..	--	3,472,331	6,113,852
Flax gill netting.....pound..	--	371	5,165
Flax measuring tapes.....yard..	31,377	36,850	5,690
Flax-hemp carpets.....square yard..	6,692	17,787	13,319
Flax-hemp artists canvas.....pound..	16,985	31,475	25,267
Flax-hemp-ramie yarns.....do..	1,815,060	--	--
Flax-hemp-ramie fabrics.....do..	--	--	--
Flax handkerchiefs.....number..	--	--	--
Flax laces, embroideries.....pound..	--	--	--
Flax sliver and roving.....do..	--	--	--
Flax liquid or gas hose.....do..	--	--	--
Flax-hemp-ramie towels.....do..	--	--	--
Flax, other manufactures[4].....	--	--	--
	Value		
Total dollars.....	--	$8,235,821.00	$9,950,862.00

Item	Quantity		
	1954	1959	1960[3]
Flax yarns.....pound..	1,085,003	1,254,571	--
Flax threads.....do..	326,047	492,502	424,850
Flax woven fabrics.....do..	261,157	289,840	--
Flax table damask.....do..	819,019	643,384	673,609
Flax-hemp woven fabrics for padding or interlining.....do..	335,746	177,778	160,317
Flax collars and cuffs.....dozen..	203	675	810
Flax-hemp sheets and pillowcases.....number..	195,754	196,089	15,987
Flax towels.....do..	3,345,781	2,977,130	2,537,503
Flax napkins.....do..	4,086,667	5,395,737	5,365,394
Flax gill netting.....pound..	4,256	2,579	6,163
Flax measuring tapes.....yard..	2,112	2,417	3,520
Flax-hemp carpets.....square yard..	44,994	48,139	96,293
Flax-hemp artists canvas.....pound..	12,680	21,345	29,471
Flax-hemp-ramie yarns.....do..	868	74,489	1,355,300
Flax-hemp-ramie fabrics.....do..	933,356	--	227,704
Flax handkerchiefs.....number..	21,433,509	23,512,490	23,916,889
Flax laces, embroideries.....pound..	173,599	191,071	--
Flax sliver and roving.....do..	120,849	1,190,246	1,240,209
Flax liquid or gas hose.....do..	20,752	265,953	318,920
Flax-hemp-ramie towels.....do..	--	131,408	58,754
Flax, other manufactures[4].....	--	--	--
	Value		
Total dollars.....	$14,034,948.00	$14,675,637.00	$15,239,465.00

[1] From (18). [2] Imports in many of the categories are reported in the 1935 source material in groupings such as "vegetable fibers other than cotton," or "flax, hemp, and ramie and manufactures," and are not shown separately for individual fibers or identified as to end products. [3] Preliminary. [4] No quantity shown; included in value data given.

market has been developed in the past few years (300,000 pounds in 1960) for cut (1 to 3 inches) flax for blending with dacron, rayon, and cotton for dresses and suits. These blends are reportedly in demand for a specialized market in which a linen-content claim has promotional value. The flax used for these blends is cleaned and prepared in accordance with mill specifications and brings from $0.50 per pound and up.

Cellulose sponges and sponge cloths.--Cut line flax (5/8 to 3/4 inches) is also used as a reinforcing agent in cellulose sponges and sponge cloths. These sponges and cloths are made from regenerated cellulose (from wood) and 15 to 20 percent of their weight is composed of bast fiber. It is reported that other bast fibers such as hemp, caroa, and jute are also used for this purpose though flax appears to be the most important in terms of quantity utilized (1,200,000 pounds of flax per year). The market for cellulose sponges (15,000,000 pounds per year) does not appear to be growing because of the competition from synthetic sponges made primarily from polyurethane foam. Also new synthetics with hydrophylic properties apparently are about to appear on the market that may take an even larger proportion of the market.

Flax prepared in accordance with the user's specifications presently sells for $0.30 per pound. These fibers must be bleached and essentially freed of shive before incorporation in the regenerated cellulose.

Currency paper.--The fibrous raw material for U.S. currency is cotton rags and imported flax noils ($0.13 per lb.) or linen waste in the proportions of 75-25, respectively. Upon occasion, decorticated domestic seed flax fiber purchased from cigarette-paper manufacturers is substituted for imported noils. The noils, however, are preferred because they contain less shive and gums and, therefore, present fewer processing problems and provide higher pulp yields. The shive and gums have no currency papermaking properties and must be removed through the use of harsh chemicals and high-temperature, long-time cooking.

About 400,000 pounds of noils plus 1,000,000 pounds of linen-thread waste and cuttings are used annually in currency making. The market for currency paper does not appear to be growing, probably because of the increased use of checks and credit cards as media of exchange.

Imported Finished and Semifinished Flax Textiles

The value of imported finished and semifinished flax textiles imported into this country almost doubled from the end of World War II to 1954 and has increased moderately since that time (table 4). In terms of physical volume, the largest increases in individual items have occurred in imports of flax-hemp-ramie yarns (almost to pre-World War II levels), flax sliver and roving, and flax liquid or gas hoses. There has also been a rather sharp increase in imports of flax-hemp carpets.

Data on prewar imports of flax products do not clearly delineate volume of a number of items. For example, flax products are included in groupings such as "vegetable fibers other than cotton" or "flax, hemp, and ramie manufactures." However, a striking change is noted since the 1930's in imports of flax woven fabrics (exclusive of toweling). In 1935 more than $11\frac{1}{2}$ million pounds of these fabrics were imported compared with about 300 thousand pounds per year since the end of the war. The reasons given by textile industry representatives for the decline in the consumption of these fabrics are: (a) linen-appearing dress and suit fabrics have been developed from rayon and cotton at a lower cost than true linen; (b) easy-care, wrinkle-resistant fabrics are further advanced for competing fibers; (c) linens are susceptible to fading; and (d) styling, rather than durability (an established linen characteristic) receives the major promotional and advertising effort of the textile industry.

PREVIOUS SUCCESSFUL COMMERCIAL USES OF SEED FLAX STRAW

Carpets, Toweling, and Garments

Seed flax bast fiber was first used for textiles in 1902, when a company in Minnesota used it as a raw material for rugs (9). From 1903 to 1908 a linen mill in Wisconsin used seed flax fiber for linen toweling.

In 1908 another plant was established in West Duluth, Minn., to manufacture 100-percent flax toweling from seed flax fiber; production continued until about 1914 (9). The management of this company decided in 1914 that seed flax fiber produced too coarse a yarn for toweling to compete effectively with line flax towels, and production facilities were converted to flax rugmaking. This company continued to manufacture linen rugs until about 1953, when financial difficulties forced the discontinuance of operations. The firm also sold decorticated fiber to cigarette-paper manufacturers.

The company in West Duluth obtained a yield of suitable rugmaking fiber (from unretted straw) of 10 percent on the original straw. The cost of the fiber, after decorticating and degumming but prior to picking and carding, was approximately $0.25 per pound. Costs of procuring, baling, storing, and delivering straw to the decorticator totaled about $20 per ton.

Seed flax bast fiber rugs are durable, but they do not have much resiliency and, accordingly, it is difficult to achieve a pile. However, a seed flax fiber rug might find a small specialized market in furnishing den rooms and in offices and rooms featuring Early American furnishings. There has been a rather sharp growth in the market for imported line flax-hemp carpets since 1950, possibly to fill the outlets formerly supplied by domestic manufacturers. More than 96,000 square yards of carpets were marketed in this country in 1960 compared with 13,000 in 1950 (table 4).

It is also reported that in the early 1940's a commercial plant was operated for a short while in Greystone, R. I., to manufacture a wide variety of coarse garments from seed flax straw. The entire process, including decortication, was conducted in New England, which necessitated the transportation of whole straw from the North Central States. The cost of handling the whole straw over these distances rather than first decorticating the straw in the production area and shipping only the bast fiber was listed as the major economic factor causing early financial failure of the undertaking.

Building Board

From the late 1940's until about 1959, substantial quantities of the residual shive from the cigarette-paper decorticating process were used in admixture with wood for the manufacture of insulation board. However, the use of shives was discontinued in favor of 100-percent woodpulp because: (1) variation in length of shive fiber from lot to lot and within lots made it difficult to form board of uniform thickness and finish, which caused off-specification boards to turn up more frequently and a 25-percent slower machine operation compared with machine speed when all wood was used; (2) board containing shive tended to catch fire more readily in the drier, with fire losses reduced 75 to 80 percent since the discontinuance of shive use; (3) shive is quite dusty, which caused complaints from employees and nearby residential areas; (4) adequate supplies of pulpwood were available at the same price as shive--$13 per ton, dry basis; and (5) separate processing lines were required for capacity operations where wood-shive blends were used because interior board requires 100-percent wood to produce the uniformly smooth finishes demanded by users, whereas exterior board does not have to meet such rigid requirements and blends could be used if the economics were favorable.

In the late 1930's and early 1940's, it is reported that wallboard was made commercially at Winona, Minn., from whole seed flax straw. There are no details indicating why this operation was discontinued.

In the fiber flax area of Belgium, France, and the Netherlands, where the competition

from wood is not so great as in the United States, the utilization of shives from fiber flax straw for board manufacture has become quite widespread. With production beginning in 1948, annual output now exceeds 75,000,000 square feet per year (2).

RESEARCH AND DEVELOPMENT EFFORTS ON COMMERCIAL USES OF SEED FLAX STRAW

Textiles

Dresses, suits, tablecloths, towels, rugs.--From 1938 to 1946 the Georgia School of Technology, in cooperation with the Tennessee Valley Authority, the Georgia Agricultural Extension Service, and the College of Agriculture conducted extensive research on seed flax fiber for the manufacture of twine and cordage, blends of cotton and cut flax fiber for dress goods and tablecloths, and blends of cotton-flax and cotton-rayon-flax for kitchen toweling. The research was conducted with both fall-windrow retted and unretted Minnesota bast fiber supplied by a cigarette paper company (5, 15, 16, 22).

The toweling research envisaged replacing line (fiber-type) flax noils with seed flax fibers and included semicommercial runs by several manufacturers then making cotton-noil towels. In the course of the work it was learned that before seed flax fiber could be blended it had to be degummed with sodium sulfide and soda ash under pressure for 1 hour. With this additional process, seed flax fiber was more costly than noils and offered no superior properties.

Georgia School of Technology obtained yields of 12 percent to straw of cut bast fiber from seed flax straw for blending with cotton for dress goods and tablecloths. The yield of bast fiber in the finished cloth, however, was only 5 percent to original straw because of losses in the spinning and fabric-making operation. In this research tests were made of the relative feasibility of cutting the fiber after decortication, carding, combing, and roving versus cutting the fiber-containing straw prior to decortication. The total cost of clean, degummed, spinnable fiber delivered to the user was $0.48 per pound, which made it out of reach for commercial development.

According to the literature, a $200,000 plant was built in Windom, Minn., during World War II that used a method developed by Mr. J. A. Johnson, Winona, Minn. (1). The plant was designed to produce fiber for toweling and rugs, but the venture was unsuccessful. However, it is reported that one of the cigarette papermakers used the plant shortly after the end of the war to produce decorticated fiber for papermaking.

A million-dollar plant for producing textiles from seed flax fiber with a method developed by P. G. Gibb (1) was also considered. The Gibb method consisted of a machine that pressed the straw flat; crimped it through fluted steel rollers to break up the woody center; opened the fibers by rubber-coated rollers to free the shives, which were brushed out by a rotating spiral steel wire brush; and delivered a clean carded fiber. In tanks controlled by steam jets, an emulsifying solution and mechanical pressure loosened and squeezed out the gum. The fiber was then washed and impregnated with a spinning emulsion. The yield of fiber to straw was reported to be 15 percent.

From 1943 to 1956 the University of Minnesota conducted extensive research and development work on the utilization of seed flax bast fiber in textiles. Minnesota obtained three patents (Nos. 2,468,771; 2,741,894; 2,883,826) as a result of this work. In the mid-1950's a company was formed and financed by several Minnesota people, including University flax researchers, to conduct the necessary pilot-plant work preparatory to commercializing the Minnesota process and to develop detailed commercial cost estimates. The bast fiber was decorticated in the flax area, then shipped to the pilot plant in the East for cleaning, degumming, spinning, and weaving. In the Minnesota process, the long bast fibers (5 to 9

inches) were separated from the short fibers by carding and combing and the long fibers degummed in the roving form for 100-percent linen fabrics, primarily suits. The residual short combing waste bast fibers were blended with cotton for dresses, suits, tablecloths, and kitchen towels.

The process proved technically feasible and the linen suit fabrics were of equal quality to such fabrics made from imported line (fiber-type) flax (10, 11). And cost estimates developed in August 1956 of a commercial operation indicated that a spinnable, degummed, long fiber and residual fiber combings in the proportions of 77 and 23 percent of the recoverable bast fiber, respectively, could be produced from fall-windrow retted straw for an average cost of about $0.35 per pound as shown in the following tabulation.

Item	Cost per pound
	Cents
Starting fiber:	
Producers net return	0.77
Retting, baling, storing, transporting	7.69
Decortication	2.20
Carding	7.00
Combing	3.50
Drawing	2.70
Roving	3.30
Degumming	7.00
Transportation	1.00
Total costs, delivered	35.66
Residual shive credit	.46
Net cost	35.20

According to the persons associated with this work, estimated returns at that time appeared to be adequate to support a commercial undertaking (2,500,000 pounds of spinnable fiber and combing waste per year). However, it was decided not to attempt commercialization because of a lack of sufficient venture capital at that time for textile enterprises where the likelihood of success was questionable.

Bagging, cordage, insulation felt.--During World War II several sugar manufacturers cooperated with Georgia School of Technology in evaluating a pilot-plant process for the manufacture of heavy bagging fabric for raw sugar as a substitute for imported jute, which was in short supply. The work proved technically feasible and the sugar mills made plans to commercialize the developments. However, at the time the contract was to be let to construct a plant, jute again became cheap and available and the project was discontinued. Seed flax fiber for bagging cost about $0.14 per pound.[4] For this use the fiber did not require degumming nor complete removal of the shive.

During World War I, the Canadian Government investigated the use of the Van Allen process for extracting fiber from seed flax straw for the manufacture of binder twine, cordage, and insulation felt. The Van Allen process consisted of chemical retting, scutching, combing, and spinning the longer fibers into cordage. The shorter fibers were manufactured into insulation felts. This process proved quite feasible technically, but it could not compete on a cost basis with sisal and manila.

Paper

Fine bond paper.--Beginning about 1957, the "cotton-content" fine paper manufacturers supported research and development, including a fiber-cleaning pilot plant, on a process for utilizing the bast fiber from seed flax straw as a substitute for cotton rags.[5] Some years prior to this, work of a related nature was conducted on techniques for making fine and banknote papers from seed flax bast fiber at the Institute of Paper Chemistry; this work resulted in Patent No. 2,641,541 (21).

Apparently, it has become increasingly difficult to obtain an adequate supply of rags suitable for papermaking since the early 1940's because of the incorporation in many fabrics

[4] Processing of Domestic Flax, Annual Report, July 1, 1942--July 1, 1943. Ga. School Technol. (Unpublished.)

[5] Flax Research Project. Cotton-Content Fine Paper Manufacturers Rpt. 1, Jan. 1958, 51 pp.; Rpt. 2, Feb. 15, 1961, 21 pp. (Unpublished.)

of synthetic fibers and of resin finishes. Accordingly, rags have become quite high in price. Since 1945, the cotton-content paper manufacturers have blended the much cheaper cotton linters with rags in the proportions of 60 and 40 percent of the total cotton content respectively. The papermakers report that the linters content cannot be increased without substantial reduction in end-product quality.

The pilot-plant work was designed (1) to develop a means for obtaining a cleaner, more shive-free bast fiber than is possible with the present cigarette-paper fiber decorticating process; (2) to provide cooperating paper mills with sufficient fiber to make commercial trial runs of pulp and paper; and (3) to develop cost information of the entire process from the straw to the finished paper. In mid-1959 this research and development work was concluded, and in October 1960 Patent No. 2,957,209 was issued covering the fiber-cleaning process developed in the pilot plant. The cotton-content manufacturers' final report (dated February 1961) on the economic feasibility of the project indicated that the technical problems had been solved or were capable of solution but that pulp made from the flax fiber was somewhat more expensive than pulp from cotton rags.

The flax fiber provided high-quality paper, but the shive content was higher than anticipated and pulp yields were disappointing. Pulp yields were 50 to 70 percent as compared with 85 percent for rags. In addition, it was learned that most of the cotton-content paper manufacturers would need to purchase some new equipment to handle the special problems of bleaching and water removal from the pulp and that the flax fiber must be cut into lengths not exceeding $1\frac{1}{2}$ inches before pulping.

The cost of flax fiber produced by the pilot plant was estimated at $0.11 per pound, delivered to the paper mill, compared with $0.15 for unbleached muslin rags. The cotton-content papermakers estimate the fiber would be competitive with muslin rags at $0.06 (assuming 50 percent pulp yield) to $0.08 per pound (assuming 70 percent yield).

Because of the high cost of cotton-content paper raw materials and increased competition from improved wood-content fine papers, the market for cotton-content papers declined immediately after World War II, but has leveled off at about 118,000 tons per year.[6] Approximately 30,000 tons of rags are required for this tonnage of paper. An equivalent amount of clean bast fiber can be produced from 225,000 tons of straw.

Currency paper.--The fibrous raw material for U.S. currency is cotton rags (75 percent) and imported flax noils ($0.13 per lb.) and linen waste (25 percent). Representatives of the currency manufacturer indicated that domestic seed flax fiber would be attractive as a substitute for noils if it could be obtained for $0.11 (assuming 70 percent yield) per pound. If the percentage of shive could be reduced to that of noils, the domestic fiber would bring an equivalent price. About 800 tons of fiber, 70 percent yield (or 5,000 tons straw), would be required for currency paper if the sole source were seed flax straw.

Coarse paper and paperboard.--Considerable work was done between 1910 and 1950 by various public agencies and private firms on the pulping of whole straw for coarse paper and paperboard (7, 12). Generally, the findings were that competing raw materials would yield better quality products at lower costs. Most organizations that looked into the pulping of whole straw believed that the presence of long bast fiber might give end products special properties not present in products made from other raw materials. However, since the shive comprises close to 85 percent of the whole straw, it is even more difficult to pulp than decorticated fiber. The bast fiber becomes gummy and weak during the harsh pulping process required and loses most of its special characteristics.

High-strength specialty papers.--Manufacturers of high-strength specialty papers, such as backing for sandpaper and tag stock, are interested in seed flax bast fiber as a raw material. The present raw materials for such papers are bleached kraft pulp at $0.075 per pound, old hemp rope at $0.085 per pound, and raw hemp at $0.18 to $0.28 per pound.

[6] Fine Paper Production by Grades. Writing Paper Manufacturers Association. Feb. 20, 1961.

Nonwoven Products

Private industry is also considering research on degummed and bleached seed flax bast fiber for use in nonwoven items such as dusting and cleaning cloths. Rayon at $0.27 per pound is the raw material with which flax would have primary competition.

Absorbent Pads

In 1956 a private firm appraised degummed and bleached seed flax bast fiber as a raw material for sanitary absorbent pads to compete with bleached cotton. The flax was found to have good properties and to be less costly than cotton ($0.40 per pound versus $0.52 per pound). However, soon after the evaluation was completed, gauze waste or cuttings came into use for absorbent-pad production at a lower cost than either flax or bleached cotton.

Cellulose Sponges

Cut-line (fiber-type) flax (5/8 to 3/4 inch) is used as a reinforcing agent in cellulose-sponge manufacture. During World War II, Georgia School of Technology, in cooperation with a producer of cellulose sponges, conducted research, on a laboratory and pilot-plant scale, for the substitution of domestic seed flax fiber for imported line flax. The seed flax fiber was rejected after considerable work because of excessive costs ($0.40 per pound in 1943) in cleaning, degumming, and cutting the fiber to the desired lengths. At the present time (1962), line flax prepared for incorporation in cellulose sponges sells for $0.42 per pound.

FEASIBILITY OF PROPOSED PROCESSES FOR UTILIZING SEED FLAX STRAW

During 1960 and 1961, several United States and Canadian firms have examined the feasibility of the Litvan process and of the proposed new Schulze processes for extending the utilization of seed flax straw.

The Litvan Process

The Litvan process, covered in Patent No. 2,721,358, granted October 25, 1955, to Jozsef Litvan and Aladar Glaser, Budapest, Hungary, is designed to extract fiber suitable for "binder twines, bookbinders' twines, parcelling twines, yarns for roughs and industrial fabrics, such as crash toweling and the like." This process is rather exceptional in that it proposes tank retting of seed flax straw in baled form from 2 to 3½ days in water at 68° to 75° F. with a pH 6.8 to 7. The fiber is then rinsed and dried to a moisture content of 7 to 10 percent. These moisture limits must be observed to obtain satisfactory decortication. Drying may be done either in a forced-air drier or in the field.

To be effective, decortication must be done in a controlled atmosphere with a relative humidity of 65 to 70 percent and a temperature of 70° F. A standard jute-softening machine containing 63 pairs of spirally grooved rollers decorticates the straw. The retted straw is passed through the machine once or twice and then over a shaker to remove the balance of the shive. The resulting fiber is then batched with any standard emulsion to achieve an oil content of about 2 to 5 percent and allowed to age for 2 to 4 weeks. Then the fiber is carded and spun.

The inventors claim the process yields 25 to 28 percent of fiber with an average length of about 8 inches and that the fiber can be produced for $0.065 per pound, delivered to user. The process is reportedly being used in several mills in Hungary.

Though the reported yield claims would indicate that the fiber contains substantial residual gums and shive, this process is being

actively examined by United States and Canadian manufacturers as a substitute for jute in the manufacture of interlinings for suits and coats and for twine and shipping sacks. At the present time (1962) most interlining is made from a blend of jute and cotton.

This search for a jute substitute was occasioned by the sharp rise in jute prices in 1960. Jute rose from an average of $0.14 per pound in the middle and late 1950's to an average of $0.18 per pound in 1960 and reached a high of $0.25 per pound. In 1961 and 1962, however, prices have declined to about $0.16 per pound. Poor growing conditions in India, the major jute producer, during 1959 and 1960, were reported to be responsible for the short supplies and high prices of the fiber. Imports of raw and manufactured jute for consumption ranged from 700 to over 900 million pounds from 1950 to 1960 (table 5). Bags and bagging, carpet and rug backing, and rope and twine were the major end uses.

The information available on the Litvan process is not sufficiently detailed to permit an evaluation of the inventor's cost claims. However, it seems clear that costs would have to be maintained at low levels for the seed flax fiber to compete with jute and jute substitutes, such as paper, kenaf, sisal, hemp, caroa, and henequen.

Paper has made significant gains as a material for bagmaking because of its low initial price and its adaptability. However, it has low re-use value and product losses are frequently high.

New developments in the knitting of paper to achieve properties desired for carpet and rug backing at a relatively low cost appear promising.

Kenaf, with properties similar to jute, is now under development, particularly in Latin America. Clean, retted kenaf fibers are about 90 percent as strong as jute and flax and will probably sell on a long-range basis for about $0.11 per pound, delivered to user. Decorticated, but unretted, kenaf is also under consideration for use in bags and would probably bring $0.06 per pound.

From 1952 to 1960 the price of sisal and henequen has dropped from about $0.20 to $0.13 per pound. Hemp, during this period, has sold for $0.18 to $0.32 per pound.

For twine and cordage, dacron, nylon, and possibly polypropylene, are expected to continue their encroachment on natural fibers, especially in industrial and marine ropes (in which hemp has been dominant), fishing lines (formerly mostly line flax), and belting cords where strength and length of service is important. In terms of fiber strength, henequen is approximately equal to that of flax and jute. Sisal and hemp are 30 to 50 percent stronger than flax and jute, but nylon and dacron range from 70 to 100 percent stronger than flax and jute.

In addition to increased interfiber competition, the overall cordage and twine market has been adversely affected by (1) the acceptance and increased use of plastic tapes, (2) the increased mechanization in agriculture lessening the demand for plow lines, (3) the increased use of home laundry dryers, which have cut the need for clotheslines, (4) the increased use of metal wire and bands for packaging, and (5) the installation of new types of windows not requiring sashcords.

The feasibility of commercializing a new bast fiber in the United States cordage industry depends on the ability of the fiber to meet: (1) the price and property attributes of sisal and henequen as related to specific use areas in twine, cordage, and ropes; (2) the price and property attributes of jute in bags and bagging, carpet and rug backing, and clothing interlining; and (3) the property attributes of nylon and dacron in uses where strength, service life, weight, and service reliability are the prime considerations.

The Schulze Processes

Leroy Schulze, holder of Patents No. 2,741,-894 (Process of Preparing Yarns), assignor to the University of Minnesota, April 17, 1956, and No. 2,957,209 (Fiber Cleaning Process), October 25, 1960, claims to have developed new and more effective approaches to seed

TABLE 5.--Jute and hard fibers: Imports for consumption in United States, prices at New York, and world production, 1950-1960[1]

Year	Jute							
	Imports for consumption						Price per pound raw jute at New York[4]	World production[5]
	Raw			Manufactured				
	Jute	Jute butts	Total	Burlap	Other[2]	Total[3]		
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Cents	Million pounds
1950...	168	6	174	419	159	578	15.5	3,824
1951...	207	29	236	334	153	487	23.1	4,531
1952...	82	17	99	483	149	632	[6] 15.2	4,692
1953...	156	52	208	435	134	569	13.1	2,971
1954...	105	20	125	416	139	555	14.1	3,407
1955...	106	11	117	475	215	690	13.1	4,484
1956...	148	21	169	526	227	753	13.3	4,619
1957...	128	5	133	495	210	705	15.4	4,200
1958...	72	12	84	488	145	633	14.4	4,628
1959...	98	57	155	574	183	757	14.9	4,144
1960...	122	([7])	122	536	221	757	18.3	4,338

Year	Abaca			Sisal and henequen				
	Imports for consumption[8]	Price per pound raw abaca at New York[9]	World production	Total imports for consumption		Price per pound raw Haitian sisal at New York[11]	Price per pound raw Mexican henequen at New Orleans[12]	Total world production
				Raw	Manufactured[10]			
	Million pounds	Cents	Million pounds	Million pounds	Million pounds	Cents	Cents	Million pounds
1950...	128	26.6	251	342	3	17.0	12.6	937
1951...	189	31.9	318	380	6	28.0	24.0	1,032
1952...	156	23.8	297	400	4	19.5	--	1,080
1953...	124	24.1	283	348	4	12.3	--	1,104
1954...	75	18.4	251	324	3	11.2	--	1,195
1955...	82	19.3	265	330	4	10.5	--	1,304
1956...	91	22.2	291	295	4	10.3	--	1,387
1957...	102	27.0	283	280	3	9.3	--	1,468
1958...	98	25.8	212	263	4	9.5	--	1,531
1959...	96	30.6	242	280	5	11.5	--	1,630
1960...	52	31.6	230	216	4	12.9	--	1,666

[1] From (19).
[2] Includes bags and bagging for cotton (new and second-hand), webbing, padding, carpets and rugs, and yarns.
[3] In some instances import statistics have been converted from yards to pounds on the basis of average weights.
[4] Prices for raw jute are for native first marks, duty-paid.
[5] Excludes Communist China, Manchuria, and U.S.S.R; and excludes mesta and other substitutes wherever possible.
[6] Price for January-July from Daily Mill Stock Reporter.
[7] Jute and jute butts combined in 1960.
[8] Raw abaca and manila cordage.
[9] Prices for raw abaca are for Davao Grade I.
[10] Sisal and henequen cordage.
[11] Prices for raw sisal are for Haitian Grade A, compiled from New York Journal of Commerce.
[12] Prices for raw henequen are for Mexican Grade A.

flax straw processing based in part on the techniques covered in the cited patents.[7] The end uses envisioned include blends of cut fiber and cotton, wool, rayon, and other fibers for apparel, cellulose-sponge reinforcement, absorbent pads, and currency and fine bond paper.

One Schulze proposal includes a new and unique retting technique--overwinter retting in the stubble and swathing and baling in the spring. It is claimed that overwinter retting in this manner is a practical method of eliminating the gums and lignins--thereby precluding the necessity of in-plant chemical degumming and permitting more effective and less costly mechanical separation of the bast fiber and shive.

There is no record of any experimental work with overwinter retting in the stubble, but flax-research and commercial-plant personnel indicate that overwinter retting in the windrow does help eliminate gums and lignins and simplify shive removal. However, none of these individuals has been successful in eliminating in-plant degumming after seed flax straw has been windrow-retted in the field, and several pointed out the danger of damaging the bast fiber by overretting. Also, it is estimated the on-farm costs of holding straw over winter in the stubble would add substantially to the cost of the starting fiber.

Another Schulze proposal is reported to involve no retting, either windrow or stubble. From the available information, it appears that the basic processing steps in each involve modifications of known decortication and carding techniques. The carded fiber is designed for the textile, nonwoven, and sponge markets and the residual carding bast fiber waste for fine bond and currency paper. The unretted fiber probably must also be degummed in some manner before it can be utilized for textile and other relatively high value uses.

Sufficient data are not available to estimate costs of the Schulze processes. Decortication, carding, and degumming costs for the most recent (1956) pilot-plant effort (University of Minnesota process) to obtain a textile fiber from seed flax straw are itemized on page 11.

SUMMARY AND CONCLUSIONS

Bast fiber decorticated for cigarette-paper manufacture (somewhat better than 33 percent yield to straw) carries an equivalent weight of gums and shive fragments and is produced and delivered to the papermaker at a cost of about $0.055 per pound. Occasionally, small quantities of the decorticated bast fiber are sold by the cigarette-paper firms for currency-paper manufacture in admixture with cotton rags. Most of the flax shive produced as a residual fraction from the decortication is dumped and burned. Limited quantities are burned as fuel (almost one-half the value of coal) in the decortication plant and marketed as a low-grade ingredient in cattle feed, as poultry and animal litter, and as a foundry conditioner for core oils.

Successful commercial uses of seed flax straw in the past included rug manufacture (1902-53); kitchen toweling (1903-14); coarse garments and other textiles (early 1940's); and insulation board from a blend of the shive (from the cigarette fiber decortication process) and wood (mid-1940's to 1959). The reasons for discontinuance of these uses are centered on competition from other raw materials providing either superior properties or lower cost in intermediate and end uses. The problems of the rug producer are reported to have stemmed more from financial difficulties than quality of end product. However, flax has little resiliency and it is difficult to achieve a pile. A small import market for fiber flax-hemp rugs has developed since the discontinuance of the domestic operation.

[7] Private communications between Mr. Schulze and representatives of the U.S. Department of Agriculture.

Proposed uses for the bast fiber reaching the pilot-plant stage were the manufacture of twine and cordage; blends of cotton and cut flax fiber for dress goods, tablecloths, and towels; and bast fiber reinforced cellulose sponges (Georgia School of Technology--1938-46); 100-percent-linen garments, primarily men's suits from the long bast fibers and cotton-flax blended fabrics from the short residual combing bast fibers (University of Minnesota-Linen Products Company--1943-56); absorbent products (1956); and as a replacement for rags in "cotton content" fine paper manufacture (cotton-content papermakers--1957-59). The delivered cost of the bast fiber appropriately cleaned and prepared for the end uses envisioned was $0.14 per pound for twine and cordage; $0.40 per pound for reinforcing cellulose sponges; $0.40 per pound for absorbent products; $0.11 per pound for fine paper manufacture; $0.48 per pound cut for blending with cotton for textiles (1938-46); and $0.35 per pound for 100-percent-linen garments and cotton-flax fabric blends (1943-56). These costs were considered out of range for successful commercialization of the various processes.

Many of the past and present efforts to commercialize seed flax have been directed toward replacing line (fiber-type) flax fiber or imported fiber-type flax semifinished or finished products.

The market for line flax fiber for textile purposes, the principal end use, has declined materially since the 1920's and 1930's and has leveled off (1959-60) at a total of about 3 million pounds annually--less than one-tenth of 1 percent of the mill consumption of all textile fibers. Since 1953 all the line flax used in this country has come from overseas sources. According to trade estimates, the end use breakdown of imported line (fiber-type) flax for textiles in 1960 was as follows: (a) 350,000 pounds of "noils" ($0.13 per lb.) and 200,000 pounds of cut "tow" ($0.30 per lb.) were blended with cotton (75 percent cotton and 25 percent flax) for kitchen toweling; (b) 620,000 pounds of "tow" ($0.20 per lb.), "not hackled" ($0.26 per lb.), and "hackled" ($0.34 per lb.) were used in making linen thread and 100-percent-linen kitchen toweling; (c) 1,700,000 pounds of "tow," "not hackled," and "hackled" fibers were used for blending with rayon and other synthetics for drapery and upholstery coverings; and (d) 300,000 pounds of cut flax were blended with dacron, cotton, and rayon for dresses and suits. In addition, about 1,200,000 pounds of cut (5/8 inch) line flax were used for cellulose-sponge reinforcement and 400,000 pounds of "noils" plus about 1,000,000 pounds of linen thread waste and cuttings were used for making paper for currency. The fiber used for cellulose sponges, bleached and freed of most of the residual shive by the importer, is sold to the user for $0.30 per pound.

The market for linen thread is continuing to lose ground to synthetics and lower priced cotton, and cotton-flax "noil" towels have made substantial encroachments on the market for linen towels. And no growth trend in the market for cellulose sponges or currency paper is evident. In contrast to these trends, the market for cut (1 to 3 inches) flax for blending with dacron, rayon, and cotton for dresses and suits, though quite small, has been growing slightly in recent years. These blends are reportedly in demand for a specialized market in which a linen-content claim has promotional value. Flax fiber cleaned and prepared by the importer, in accordance with mill specifications, brings $0.50 per pound and up delivered.

Most of the finished or semifinished flax fabrics imported into this country require a fineness and length of fiber characteristic of line rather than seed flax. These include 100-percent-flax handkerchiefs, table damask, sheets and pillowcases, napkins, shoe thread, and fishing line. In the aggregate, the value of these materials almost doubled from 1946 to 1954, but it has leveled off since that time. A striking change is noted since the 1930's in imports of flax woven fabrics. In 1935 more than $11\frac{1}{2}$ million pounds of these fabrics were imported compared with less than 300,000 pounds per year since the end of the war. The reasons given by representatives of the textile industry for the decline in the use of 100-percent-flax fabrics include: (a) linen-appearing dress and suit fabrics have been developed from rayon and cotton at a lower

cost than true linen; (b) easy-care, wrinkle-resistant fabrics are further advanced for competing fibers; (c) linens are susceptible to fading; and (d) styling, rather than durability (an established linen characteristic), receives the major promotional and advertising effort of the textile industry.

One of the fiber-cleaning and processing techniques presently being examined by U.S. and Canadian firms is covered in Patent No. 2,721,358, held by Jozsef Litvan and Aladar Glaser, Budapest, Hungary. It is reported that the inventors claim a yield of 25 to 28 percent bast fiber and that the fiber can be retted and processed and delivered to the user for $0.065 per pound. The intended uses for the fiber are cordage, twine, and interlining for apparel. The process is reportedly being used in several mills in Hungary.

Leroy Schulze, holder of Patents No. 2,741,-894 (assignor to Regents of the University of Minnesota) and No. 2,957,209, claims to have developed a process, or processes, that will yield fiber of satisfactory quality at costs that will make it competitive with other raw materials for fine bond paper, currency paper, textile blends, nonwoven products, absorbent pads, and cellulose-sponge reinforcement.

Sufficient details are not available on either the proposed Schulze or Litvan processes to evaluate the cost estimates of the inventors. However, assuming large-scale utilization of the available straw, it is estimated that decorticated, carded, and retted, or chemically degummed, fiber from seed flax will bring the following delivered prices for the indicated end uses: $0.23 per pound in textile blends, nonwoven products, and cellulose-sponge reinforcement; $0.11 per pound for cordage and interlining; $0.06 per pound for the carding waste for bond paper (if 50 percent pulp yields can be obtained). Decorticated, carded, drawn, combed, and retted, or chemically degummed, fiber should bring $0.27 per pound for textiles, nonwovens, absorbent pads, and sponge reinforcement and the residual combing waste $0.08 per pound for fine bond paper (if 70 percent pulp yields can be obtained) and $0.11 per pound for currency paper (assuming 70 percent pulp yield). Fiber that is decorticated only would probably not be sufficiently free of shive and gums for high-value uses. For paper, the value of the fiber would be dependent on its cleanness and the pulp yields obtainable. For bagging, a decorticated but unretted or degummed, fiber would sell for about $0.06 per pound, delivered.

Estimates of probable returns for the bast fiber in various end uses were developed on the basis of appraisals by potential users and distributors and by U.S. Department of Agriculture and U.S. Tariff Commission textile and paper specialists. The estimates assume that any commercial venture would set out not only to replace imported line (fiber-type) flax, but to create greatly expanded markets. Mere replacement of the line flax market would only utilize 15,000 to 18,000 tons of straw. To achieve any large-scale utilization of the 480,-000 tons of unused seed flax straw, the fiber will have to be marketed on a price basis competitive with other fibers.

The markets for seed flax fiber that appear to hold the most promise for substantial utilization are its use as a substitute for cotton rags in specialty papers such as fine writing paper, stock certificates, currency and other documents requiring durability, and possibly in specialty types of saturating papers for backing for sandpaper and pressure-sensitive tapes.

If the supply of suitable rags (free of resin finishes and synthetic fibers) continues to shrink, the cotton-content papermakers will have to seek alternate fibers for the rag fraction (the cheaper cotton linters comprise 40 percent of the total cotton content) such as flax and hemp or possibly the newly-developed hydroxyethylated softwood sulfate pulps. Rags and seed flax fiber would be roughly in equilibrium (if the papermaking fiber-cleaning process developed in pilot-plant work by the cotton-content papermakers in 1957-59 were used) if the 30 percent cost differential between seed flax fiber and rags disappears either by mounting prices of rags, the development of further efficiencies in flax fiber cleaning, a flax fiber freer of shive, or some combination of these factors. Assuming complete displacement of cotton rags, the market for rag-content fine paper and currency paper would take the fiber from 230,000 tons of straw annually.

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